COMMERCIAL AND INDUSTRIAL BASE INTERMITTENT RESOURCE MANAGEMENT PILOT

Scoping Study

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ABSTRACT
This scoping study summarizes the challenges with integrating wind and solar generation into the California's electricity grid. These challenges include:

- Smoothing intra-hour variability
- Absorbing excess renewable energy during over-generation periods
- Addressing morning and evening ramping periods

In addition, there are technical challenges to integrating retail demand response (DR) triggered by the wholesale conditions into the CAISO markets. The study describes the DR programs available to the consumers through the utilities in California and CAISO's ancillary services market because an integration of the wholesale and retail DR requires an understanding of these different offerings and the costs associated with acquiring them. Demand-side active and passive storage systems are proposed as technologies that may be used to mitigate the effects of intermittence due to renewable generation. Commercial building technologies as well as industrial facilities with storage capability are identified as targets for the field tests. Two systems used for ancillary services communications are identified as providing the triggers for DR enablement. Through the field tests, issues related to communication, automation and flexibility of demand-side resources will be explored and the performance of technologies that participate in the field tests will be evaluated. The major outcome of this research is identifying and defining flexibility of DR resources and optimized use of these resources to respond to grid conditions.

Keywords: Intermittent renewable resources, variable generation, demand response, automated demand response, OpenADR.

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1 EXECUTIVE SUMMARY

California is pursuing the development of renewable energy technologies. Renewable Portfolio Standards pushed by the California State Legislature and the Governor mandate 20% renewable generation by 2017 and 33% by 2020. Much of the growth in renewable resources will be met by increased wind and solar capacity. However, grid operators are concerned at the integration challenges posed by the variable generation profiles of resources. Specifically, they pose four operational challenges for the CAISO:

- The magnitude of hourly overall ramping requirements
- Intra-hour variability
- Over-generation issues (particularly wind)
- Large, near-instantaneous production ramps (particularly solar)

The IRR pilot project will harness the potential of demand response and demand-side storage capabilities--thermal mass, process mass, chilled water storage, and dimmable ballast lighting--to cost-effectively provide load following and ramping products that the CAISO will need to manage the grid under increased renewable generation. It will build on past research that the DRRC has conducted utilizing Open Automated Demand Response (OpenADR), focusing on using demand-side storage capabilities in commercial and industrial facilities. The main contribution of the IRR pilot will be a greater understanding of the critical role that automated demand-side resources and OpenADR can play in moving California to a greener energy system through facilitating renewable integration.

The report has six sections. We begin by analyzing the specific challenges that increased amounts of variable generation pose for the CAISO. In Section Two, we provide some high-level description of California demand response programs and discuss how scenarios of heightened renewable penetration may affect program requirements. The Third Section outlines the path of renewable integration in California and discusses some of the obstacles that may lie in the way. Sections Four and Five provide a description of retail DR programs and an introduction to wholesale ancillary services in California. Section Six explores appropriate end-uses for renewable integration. In Section Seven, we provide an outline of the proposed field tests and summarize possible challenges that may arise.

2 BACKGROUND

Pacific Gas and Electric (PG&E), an Investor-Owned Utility (IOU) based in San Francisco, California, is one of the largest natural gas and electric utilities in the United States. PG&E provides natural gas and electric service to approximately 15 million people throughout a 70,000-square-mile service area in northern and central California. PG&E is working to develop innovative programs for integrating intermittent renewable resources through two California Public Utilities Commission approved projects [A.08-06-001, A.08-06-002, & A.08-06-003]: the C&I Base Intermittent Resource Management Pilot, and the PHEV/EV Smart Charging Pilot. This paper is the scoping study for the C&I Base Intermittent Resource Management Pilot, hereafter known as the Integrating Renewable Resources (IRR) Pilot.

Renewable energy resources, such as wind, solar, geothermal, and small hydro are a growing part of utility portfolios. They bring value through the displacement of fossil fuel consumption and limit exposure to volatile fossil fuel prices, act as a hedge against possible greenhouse gas regulations. Wind and solar are the fastest growing renewable resources, with 35,159 MW of wind and 9,183 MW solar installed in the US (Solar Energy Industries Association 2008). Renewable energy sources such as geothermal, biomass and small hydro are predictable and have capacity factors around 80-90%. In contrast, wind and solar are significantly more variable and have capacity factors of typically less than 30%.

California is a national leader in the development and integration of renewable energy technologies. In 2002, the California State Legislature adopted one of the first Renewable Portfolio Standards in the United States, setting a target of 20% renewable generation by 2017. Just after, the target date was accelerated to 2010. With all of California's Investor-Owned Utilities (IOU) on track to meet the 20% mark, the California Governor went one step further by issuing Executive Order S-14-08. This set an even more aggressive target of 33% renewable energy by 2020. Furthermore, the governor directed the California Air Resources Board (CARB) to officially adopt regulations increasing California's RPS to 33% by 2020 through Executive Order S-21-09 (California Public Utilities Commission 2009).

At the end of 2009, there were 2935 MW (CAISO, 2009) of wind capacity interconnected to the CAISO and a projected 4,000 MW coming on-line by 2012. Additionally, over 1,000 MW of solar thermal, concentrating solar and photovoltaic, are expected to be deployed (KEMA, 2010). The growth in variable generation requires changes in how the wholesale grid is managed. Even though emerging electric vehicle and storage technologies may address the issue of renewable integration, demand response resources, which are currently deployed on the grid, can potentially provide these services at a lower cost.

In 2009, PG&E's Participating Load Pilot moved three automated demand response (AutoDR) participants into ancillary services non-spinning reserves where they participated successfully (see Section 4.2). The IRR pilot project aims at further developing demand response resources to facilitate renewable resources integration.

2.1 INTEGRATING RENEWABLE RESOURCES (IRR) PILOT PROJECT PROPOSAL AND GOALS

The PG&E C&I Base Intermittent Resource Management Pilot is a collaborative effort between PG&E, LBNL's PIER DRRC Center and CAISO. It aims to address the challenges and opportunities of integrating over 6,000 MW of variable generation resources. The primary objective of this pilot is to determine the feasibility of demand side storage capabilities—thermal mass, process mass, ice and cold water storage—to provide load following and ramping products that the CAISO will need to manage the grid under a 33% RPS. This pilot will build on past research that the DRRC has conducted utilizing Open Automated Demand Response (OpenADR) in commercial and industrial facilities and providing non-spinning reserves to the CAISO.

The project team will consist of PG&E, Akuacom, Lawrence Berkeley National Laboratory (LBNL) and the CAISO. Additional team members may be added during the site selection and implementation phases. Responsibilities of the team members are as follows:

- PG&E – Project management, market design and infrastructure needs
- LBNL – Develop scoping study, site selection criteria, recruitment of sites, evaluation of building controls issues and DR control strategies
- Akuacom – Automation of AGC dispatch signals, conversion from AGC specific format to OpenADR
- CAISO – System Operator and dispatch of event signals.

This report is divided into six sections. The First Section analyzes the electric supply issues specific to the CAISO's integration of large volumes of variable generation and the current state of DR programs in California. Section Two discusses how these electrical supply issues change DR program requirements. Section Three summarizes the integration of renewable resources in California and outlines some of the road blocks they may face in implementation. Sections Four and Five describe the retail DR programs and wholesale ancillary services products in California respectively. Section Six identifies and describes the end uses appropriate for renewable integration. Finally, in Section Seven, we outline the proposed field tests and summarize the challenges to implementation.

3 Renewable Generation in California

3.1 The Impact of Renewable Generation on the CAISO Grid

In 2007, California's renewable resources (wind, solar, geothermal, biomass, small hydro, and biogas) generated a total of 27 TWh. While this level of renewable generation is a significant accomplishment, an additional 75 TWh will be needed to meet the augmented standard of 33% by 2020 (total of 102 TWh) (CPUC 2009). The bulk of these resources will be either wind or solar, which provide energy at a variable rate based on environmental conditions.

Integrating variable generation resources requires additional supply and demand flexibility to accommodate faster ramping periods and increased forecast error. In their 2007 *Integration of Renewable Resources* report, the CAISO concludes that "integrating 20% renewable energy in the California electric power system is operationally feasible; however, changes to operating practices will be required" (Loutan and Hawkins 2007). These changes are driven by the specific generation portfolios of the two dominant resources: wind and solar. Wind and solar exhibit great variability and uncertainty in energy output for any possible time scale. Power system operations have already been designed to accommodate some of the variability associated with load fluctuations. However, the combined variability of load and renewable generation can significantly alter system conditions (NERC 2009).

Variable generation resources cause four specific operational challenges for the CAISO (CAISO, 2010a):

- The magnitude of hourly overall ramping requirements
- Intra-hour variability
- Over-generation issues (particularly wind)
- Large, near-instantaneous production ramps (particularly solar)

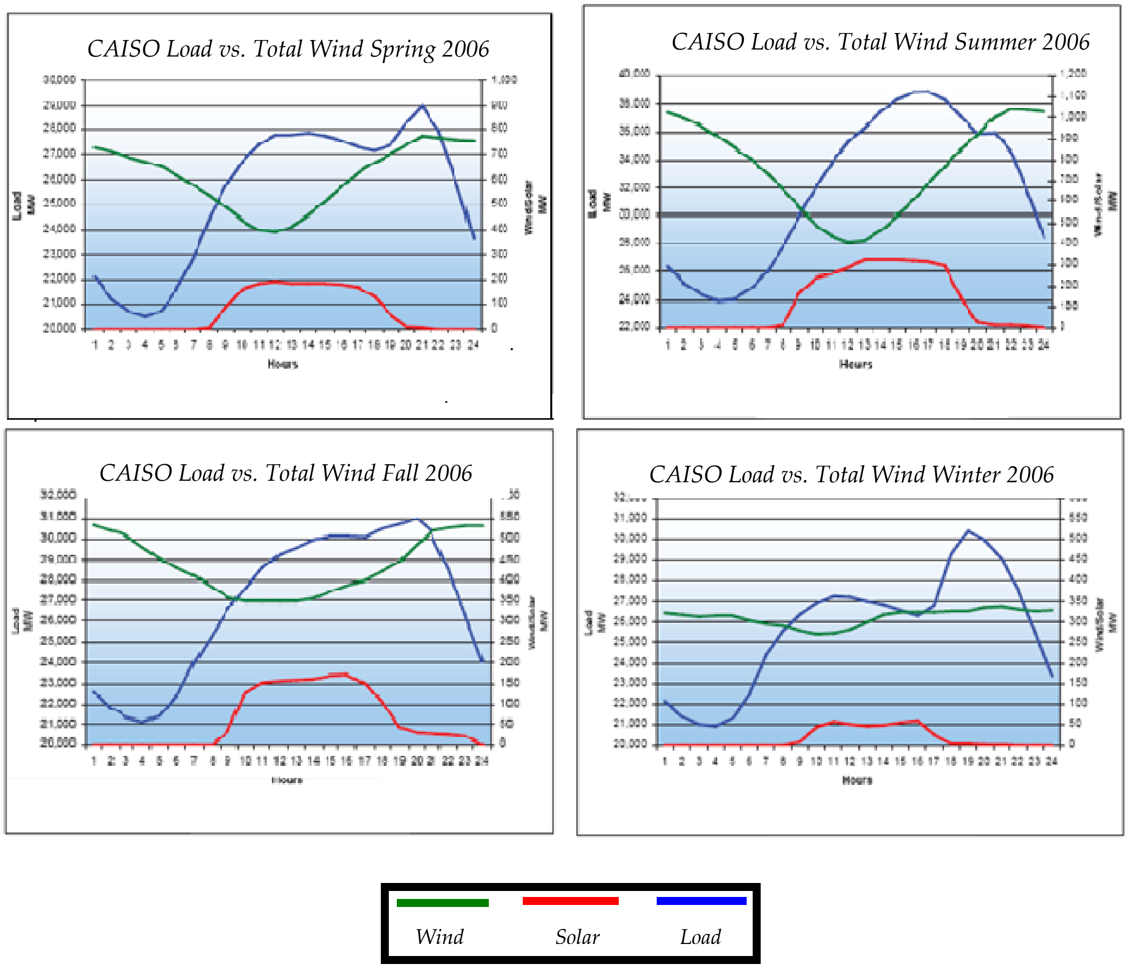
These challenges must be addressed concurrently. As the CAISO points out, "large amounts of regulation by itself does not solve the ramping problem for 33% Renewable integration" (Loutan and Hawkins 2007). Rather, flexible supply and demand, improved forecasting, and changes in grid operations are all needed. This section of the report analyzes each of these issues after a brief discussion of the generation profiles of wind and solar.

3.2 Impact of Wind

Wind energy has been the dominant renewable resource in California's generation portfolio, representing 2,935 MW of installed capacity (CAISO 2010b). Wind capacity is expected to increase to 4,200 MW with a 20% RPS.

Wind generation patterns differ substantially by season and day. Figure 1 illustrates average wind conditions by season, as documented by the CAISO.

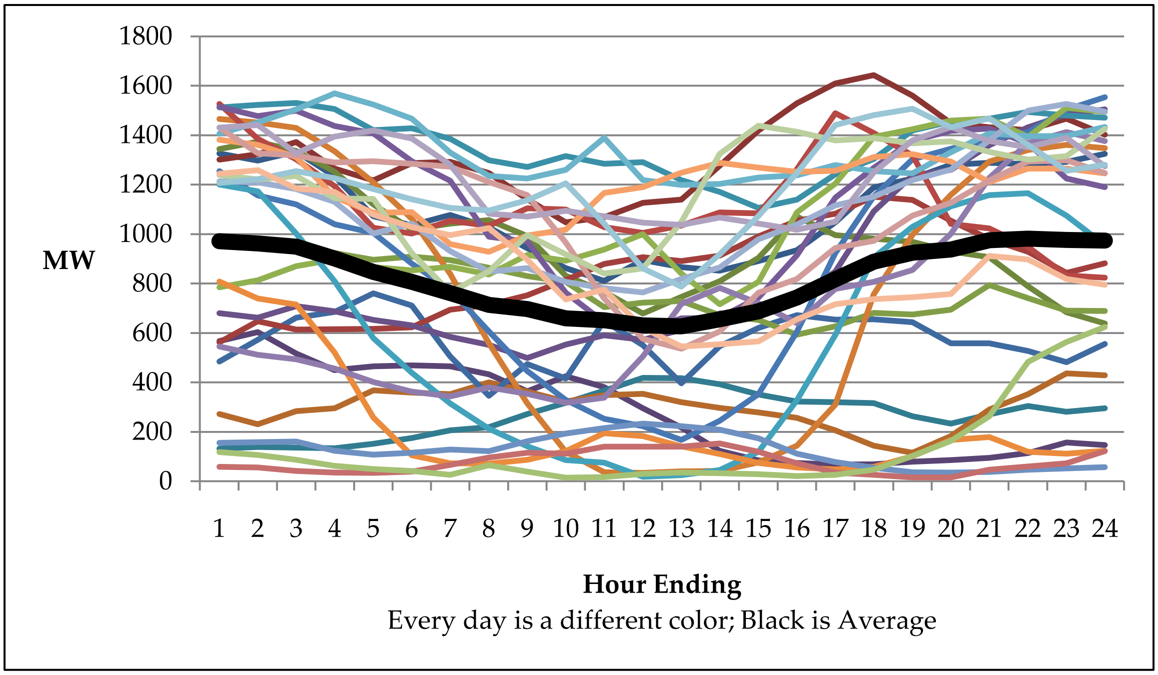
Figure 1: Wind and Solar Generation vs. Load in the CAISO, 2006



Source: CAISO 2007 Intermittent Renewables Integration Report

Figure 1 shows that wind has a pronounced diurnal (low days/high nights) average output in the spring and summer months, and a flatter average output in the fall and winter. However, it is important to note that these are average generation profiles; even within a season, there is significant variation in wind generator output. The day-to-day variation of wind generation is illustrated in Figure 2.

Figure 2: Day-to-Day Wind Variability



Source: April 2009 Wind Generation in the CAISO

These patterns (or lack thereof) illustrate the need for both accurate forecasting and resource flexibility to accommodate wind variability. Utilities and ISOs have decades of experience forecasting electricity demand. However, their experience forecasting wind generation is considerably shorter. Even after significant improvements in the reliability of wind forecasting, the day-ahead forecasting error for wind in the CAISO is around 20% (Hawkins 2010). The error in the day-ahead load and wind forecasts can have a significant impact on CAISO operations, underscoring the need for flexible reserves and resources.

The CAISO's day-ahead forecast utilizes neural-network forecasting software and multiple weather forecasting data sources. The day-ahead hourly load forecast is developed 14 hours before the operating day in order to help schedule generating resources in the day-ahead market. Because demand is weather-sensitive, accurate weather forecasting is essential to reducing forecasting error. For example, for average temperatures over 100°F, a forecast error of one degree can result in a 980 MW over or under estimation of load (Loutan and Hawkins 2007). Even though grid operators have decades of experience accommodating error in the load forecast, adding the forecast error on the generation side with wind and solar might compound the potential magnitude of this discrepancy. The additional inaccuracy can result in a misallocation of resources in the day-ahead market or in the purchasing of additional reserves for the CAISO.

Although wind resources are not currently required to bid in the Day-Ahead Market (while it is mandatory in Real-Time Market), wind generation is frequently scheduled at a quantity that differs from the CAISO forecast. The difference between scheduled and actual generation can lead to fluctuations in the real-time market price or over-generation situations. For example, if 2,500 MW of wind resources show up in a real-time market where only 2,000 MW had been scheduled the day before, the CAISO is left with 500 MW in the grid. Over-generation can significantly depress the relative market price for two reasons: 1) a surplus of energy lowers the market price in general; 2) the Production Tax Credit of $20/MWh allows wind generators to keep on producing and further depressing the prices.

Over-generation occurs when generation exceeds load and cannot be reduced. Integrating wind poses significant over-generation challenges because wind plants produce the most electricity at night when loads are low. Over-generation is most common when: 1) spring load conditions are light; 2) all nuclear plants are on-line; 3) hydro generation is high due to spring run-off; 4) long-start thermal units are on-line and running at minimum levels because they are required in future operating hours; and 5) imports on the interties are heavy (Loutan and Hawkins 2007).

In situations where load and generation are unbalanced, the CAISO automatically dispatches units on Automatic Generation Control (AGC) to new operating points. In over-generation situations:

> *"Regulating units are moved to the bottom of their regulating range, and the Real-Time Economic Dispatch System drives units with decremental (DEC) bids to their minimum operating points. At times, operators may run out of DEC bid and have to go out of market to drive the units down further or command units to shut down. Over-generation occurs whenever…the controllable generation and imports are at their minimum levels or are shut down, exports are maximized, and the total net generation production still exceeds the system load"* (Loutan and Hawkins 2007).

In 2006, there were 45 hours of over-generation. This amount is expected to grow as more wind comes on-line.

While wind generation can create integration problems for system operators, it also creates market opportunities for new resources such as flexible loads and storage. We will explore these opportunities in detail during later sections.

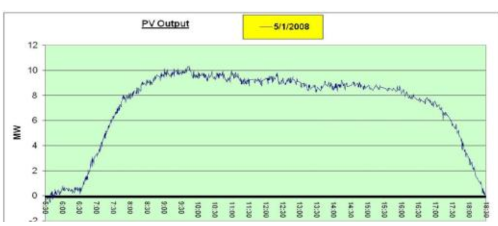
3.3 THE IMPACT OF SOLAR

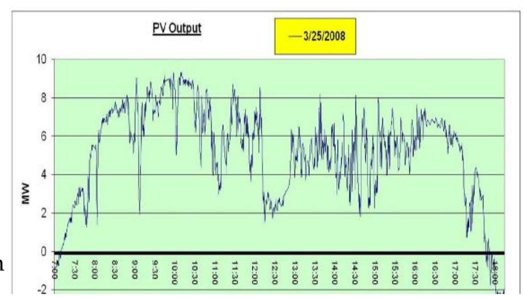
While solar generation represents less than 1000 MW today, it is expected to grow to 3,000 MW by 2012 (Hawkins 2010). Solar resources in California can be divided into two broad categories: distributed and utility-scale solar. Distributed solar is primarily Solar Photovoltaic panels (PV); utility-scale solar can be solar PV, concentrated solar, or solar thermal. Despite the fact that solar PV is typically more geographically distributed, high concentrations can pose integration problems similar to those of utility-scale solar (Hawkins D., 2010). Solar integration shares some of the same challenges with wind, such as intermittency and forecasting error. However, it also presents its own challenges: particularly large, near-instantaneous ramps.

As seen in Figure 1 Wind and Solar Generation vs. Load in the CAISO, 2006 above, solar production follows a diurnal and seasonal pattern. Solar output generally peaks during the day in the middle of summer and its production pattern is well correlated with CAISO peak demand.

The primary issue with integrating solar into the CAISO grid is addressing large, near instantaneous ramps. PV and many other types of solar thermal do not involve a rotating mass and therefore do not have inertia[1]. As a result, PV systems can experience a change in output of +/- 50% over 90 seconds and up to +/-70% in five to 10 minutes (NERC 2009). Concentrating solar plants can store thermal energy in the mass of the working fluid and thus may have less dramatic ramps. Figure 3 illustrates the difference in output between a sunny and cloudy day for a solar PV plant .

Figure 3: Solar PV Output on a Sunny Day (left) and Cloudy Day (right)





Source: NERC, 2009: Output from Nevada PV Plant on

During the cloudy day, the PV output ramps by over 50% at 9:00, 12:00, and 14:00[2]. These ramps follow two distinct patterns. During the 9:00 and 14:00 ramps, the output drops by ~50%, but then jumps back +50% within a few minutes. However, in the 12:00 ramp, the output drops by 50% and stays low for ~40 minutes. The challenge for system operators is predicting the duration of the ramp since miscalculations can result in units being unnecessarily dispatched to make up for short-term losses. Demand response can play an important role in providing short-term load reductions to match the solar ramp, allowing system operators to determine if dispatching thermal units is warranted

[1] Parabolic troughs and other designs that utilize a working fluid do have thermal inertia

[2] While this PV resource is 10 MW, similar ramps and production patterns have been experienced by the CAISO with 300 MW concentrating solar resource. See (CAISO 2009)

(Hawkins 2010). In addition, forecasting error also contributes to the challenge of addressing solar ramps. Solar output on cloudy days is more difficult to forecast.

3.4 COMBINED IMPACT OF WIND & SOLAR

Today, wind and solar power account for over 3000 MW of generation in California. While these resources have different generation profiles, it is important to consider the net impact of both types of variable generation because each resource's variability may either cancel or compound the total system variability. As NERC points out,

> *"solar energy…output may be complimentary to the output of wind generation and may be produced during the peak hours when wind energy production may not be available….Solar and wind plant profiles when considered on aggregate can be a good match to the load profile and hence improve the resulting composite capacity value for variable generation"* (NERC 2009).

Furthermore, the CAISO points out that solar can mitigate the decline of wind generation during the morning ramp period and shift the evening ramp-up of wind generation (CAISO 2009a). On average, wind and solar are complimentary and reduce the overall ramping requirements.

However, there are many days when wind and solar follow the average production schedule. As is clear from Figure 2 above, wind generation patters can vary substantially from day-to-day. Thus, the ISO frequently faces days where wind and solar are not complimentary. For example, if wind ramps down during the time before solar production begins, the ISO will have to dispatch thermal units to bridge the gap. At projected penetration levels for 33% RPS, this could result in thermal units ramping up hundreds of MW, only to ramp down again. These units would incur start-up and shut-down costs, adding to the overall costs of the power system. For these reasons, wind and solar generation must be considered in aggregate.

Additionally, load variability can cancel or compound total system variability. At low levels of penetration, wind is treated as "negative load." In terms of system variability, if wind and/or solar are moving in the same direction as load, all other generating units can remain at the same output. Thus, to express total system variability, we have the following equation:

$$\textit{LOAD} - \textit{WIND} - \textit{SOLAR} = \textit{NET SYSTEM LOAD}$$

Understanding total system variability helps frame the increased ramping challenges:

- The magnitude of ramping requirements: 3000 – 4000 MW of regulation / ramping services from "fast" resources in the scenario of 33 percent renewable penetration in 2020
- The ramping requirements twice a day or more require much more response and will be the major operational challenge.

These ramps are driven by the combination of wind ramping down while load is ramping up. The modeling efforts indicate that the amount of regulation and imbalance energy during ramping periods without storage for a 33% RPS is about 4800 MW (KEMA 2010)

The first challenge is to address the increased magnitude of overall hourly ramping requirements. One factor that makes the magnitude of ramping requirements particularly difficult for the CAISO is the geographic proximity of wind and solar resources. Because variable generation is concentrated geographically, the total output from variable generation resources are closely correlated. Consequently, the integration benefits of geographic diversity are not present. Several studies have shown that wind forecasting error can be reduced by as much as 30% to 50% when aggregating over a large geographic region (Milligan and Kirby 2007) (M. Milligan, B. Kirby, et al. 2009). As a result, the CAISO experiences steeper ramps and larger forecasting errors than other balancing authorities with similar levels of penetration spread over larger areas (i.e., Germany or Spain).

With geographic concentration in Tehachapi, the majority of the CAISO wind fleet ramps simultaneously. The CAISO estimates that

> *"by the time 20% RPS is met, a combination of load increase in the morning hours and a decrease in wind production during Hour Ending (HE) 8 through HE 10 in the summer months could result in the need to commit about 12,664 MW of capacity in the Day-ahead market, or have adequate short start and fast start resources available to commit in Real-time. Similarly, a combination of load drop-off in the evening hours and an increase in wind production during HE 22 through HE 24 could result in the need to curtail about 13,500 MW of generation"* (Loutan and Hawkins 2007).

4 INTEGRATING VARIABLE GENERATION THROUGH DEMAND RESPONSE (DR) PROGRAMS

The existing building stock represents an important and cost-effective potential resource to facilitate the integration of variable generation. Studies by Eto and Callaway outline the technology and strategies for residential buildings. Previous work by the DRRC (Piette et al. 2004 - 2010) concentrates on commercial and industrial (C&I) facilities. While this potential exists across all sectors, this study focuses on the potential in large commercial and industrial facilities (over 200 kW).

At 37%percent of peak demand, the commercial sector contributes the largest share of peak with 16,650 MW. HVAC represents 13% percent, or 6,212 MW. Ten to fifteen percent of commercial loads are good candidates for DR, with over 60 MW currently enrolled in AutoDR programs in California. Some commercial buildings in California have installed ice or chilled water systems for offsetting demand during peak periods. Other buildings have demonstrated that load can be reliably shifted off peak through pre- cooling thermal mass.

California's industrial sector represents 20 percent of electricity peak demand, or approximately 8600 MW. Preliminary estimates indicate that 30-40 percent of industrial loads may be candidates for open automated demand response (PIER Demand Response R&D Strategy 2006). Additionally, industrial facilities are good candidates for this pilot because many of them operate year round, providing a resource that would be available outside the traditional peak period.

The IRR Pilot focuses on large C&I facilities because there is both significant per-facility potential and past experience with DR programs. The large C&I facilities also tend to have sophisticated controls systems that allow for direct, automated responses to control or price signals from the CAISO.

4.1 Types of DR Programs

PG&E offers price-based and reliability- based DR programs. As of October 2010, these programs are as follows:.

• Incentive-based DR programs:

- Scheduled Load Reduction Program
- Optional Bidding Mandatory Curtailment
- Base Interruptible Program
- Capacity Bidding Program
- Aggregator Managed Portfolio

• Price-based DR programs:

- Peak Day Pricing (all customers above 200 kW are defaulted into this tariff as of May 2010)
- Peak Choice
- Demand Bidding

The IRR project focuses on ancillary services market programs. However, it is valuable to understand the full range of programs available for large C&I customers in California.

Reliability-based DR programs were the first DR programs introduced to the market and are the most widely utilized today.

Notification of DR event periods typically takes place either the day-ahead or day-of the DR event.

Price-based DR programs utilize variable pricing to offer customers varying electricity prices on a day-ahead or real-time basis. FERC notes that, "with dynamic pricing, electricity prices are either not known with certainty ahead of time, or known higher prices occur at times that are not known ahead of time"(FERC 2006). California has been introducing dynamic pricing, beginning with the Statewide Pricing Pilot for residential customers in 2003-2004. In June 2010, all customers over 200 kW are placed on a default Critical Peak Pricing tariff, also known as Peak Day Pricing. Customers in California are notified of "critical day" events on a day-ahead basis. As of end of 2009, PG&E has 230.9 MW of DR enrolled in price-based DR programs.

DR programs in CA focus on reducing energy during the summer peak with advance notice of at least thirty minutes. While these are valuable programs that support the delivery of low-cost reliable energy, new programs are emerging that utilize demand response on a shorter time scale in order to provide ancillary services to the wholesale market. In 2009, all three investor-owned utilities in California ran pilot projects that utilized demand response to provide non-spinning reserves. These were projects in California which utilized demand reductions—not customer back-up generation—to provide non-spinning reserves.

4.2 PG&E Participating Load Pilot[3] (PLP)

PG&E's PLP proved the technical feasibility of bidding large commercial and industrial DR resources into the CAISO's Day-ahead market for ancillary services non-spinning reserve. It also showed that this participation could be enabled at no additional costs for Auto-DR facilities.

The PLP model relies on a simple price-sensitive demand curve submitted in the Day-ahead market, accompanied by a pseudo-generator supply curve representing the DR resource's real-time energy dispatch capability for use in the Real-time market. Three facilities--a retail store (IKEA), a local government office building (Contra Costa County), and a bakery (Svenhard's Swedish Bakery)--were recruited for PG&E's pilot program.

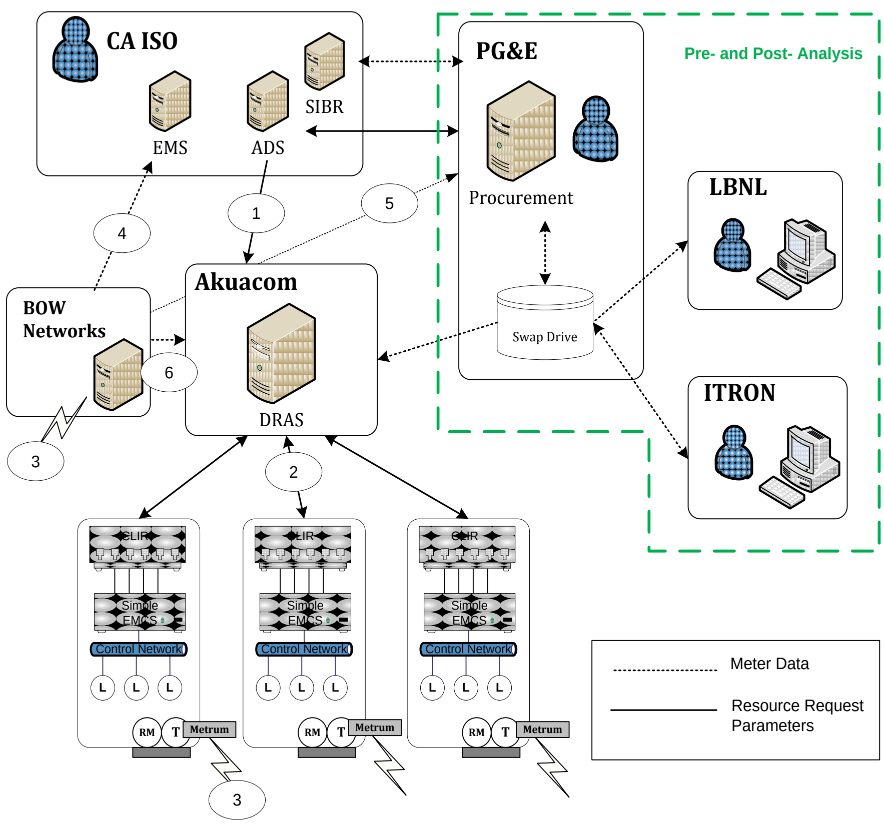
CAISO's Automated Dispatch System (ADS) linked the ISO operators dispatching DR resources to the Demand Response Automated Server (DRAS). When CAISO dispatched awards for the participants, OpenADR (Open Automated DR), which is an

[3] This section is adapted from a previous publication for the Grid Interop, (Kiliccote, et al. 2009).

information exchange model to communicate DR events, was utilized to deliver DR signals to the facilities' energy management and control systems (Piette et al. 2009). This is the same infrastructure that is currently being used for PG&E's price-based Auto-DR programs such as Automated Peak Day Pricing (successor of Critical Peak Pricing) and Demand Bidding programs. Pre-programmed DR strategies were triggered without a human in the loop at each facility utilizing the Client Logic with Integrated Relay (CLIR) box[4]. This device communicates price and reliability signals with facility EMCS by mapping DR program information to dry contact relay closures.

On the metering side, dual meter socket installations allowed the facilities to keep their revenue meter (RM). They also facilitated the installation of another meter with a Code Division Multiple Access (CDMA) chip provided by Metrum Technologies to transfer four-second electric load data for this pilot. CDMA technology transmits radio signals over a cellular-based wireless network. This four-second telemetry infrastructure was installed at each of the participating facilities in order to provide visibility to CAISO as one of their requirements. Data were communicated by Bow Networks to CAISO, PG&E and Akuacom.

Figure 4: Participating load pilot system architecture



[4] Technical guide is available at http://drrc.lbl.gov/pubs/CLIR-UserGuide_6-R3.pdf

Communication steps numbered in the figure above are:

1. CAISO issues a PL event for a resource
2. The DRAS converts this message into OpenADR and publishes over the Internet
3. The sites poll the server every minute and trigger pre-programmed control strategies.
4. (5,6) The telemetry data is collected and communicated to the CAISO, DRAS and PG&E's procurement.

The PL pilots represent an important step for DR, essentially proving that loads can have the same response characteristics as generators. The CAISO recognized two significant milestones in their assessment report:

First, the PLP project affirmed that customers with Auto-DR capability can automatically respond to dispatch instructions issued by the ISO and curtail loads, based on pre-defined instructions, with no human in the loop.

The second milestone achieved was demonstration that a real-time feedback mechanism would enable the fine-tuning of load curtailment so that the PL resource could more tightly follow ISO dispatch instructions. For example, if the primary demand response mechanism of a demand response resource is cycling air-conditioning load through temperature reset, additional "tuning" may be accomplished through dimming lighting loads or incrementally adjusting the temperature reset, up or down, based on the load curtailment feedback that the resource is sending to the resource operator's load management system (CAISO 2009c).

The IRR project will build off the PLP's success, utilizing the proven, fast reductions achieved in this pilot to provide intra-hour smoothing of variable generation resources. The DR resources participating in the PLP were able to achieve an average ramp rate of 0.25 MW/min (best 0.05; worst 0.1) (Kiliccote, et al. 2009), and were able to initiate the response within 47 seconds.

5 Ancillary Services in the CAISO Market

As this project is focusing on utilizing DR to provide Ancillary Services (AS) to the CAISO market, it is important to understand what these services are and how they are procured.

Ancillary Services in the CAISO market are regulation, spinning reserves, non-spinning reserves, voltage support and black start. Together these ancillary services support the transmission of energy while maintaining the reliable operation of the CAISO

Controlled Grid in accordance with WECC standards. Operating Reserves[5] are the combination of the two categories--regulating reserves and contingency reserves--which are required to meet NERC and WECC reliability standards. These are the reserves that a system operator relies on to ensure that the system has sufficient capacity "in-waiting" to balance load and generation in real time should a contingency event occur[6].

5.1 Definitions

5.1.1 Regulating Reserves

Regulating Reserves provide second-to-second balancing of load and generation under normal conditions. The CAISO requirement for regulating reserve is "spinning reserves, instantaneously responsive to Automatic Generation Control (AGC) to allow the Balancing Authority to meet NERC Real Power Balancing Control Performance" (CAISO 2010c). AGC is a signal from the CAISO's real-time Energy Management System. It is used to control a resources power output within a prescribed area in response to a change in system frequency, tie-line loading, or the relation of these to each other. AGC acts to maintain the target system frequency and the established interchange with other Balancing Authority Areas within predetermined limits. Regulating reserves are utilized to maintain system frequency at 60 Hz.

Regulating Reserves are dispatched through AGC in response to frequency and net interchange deviations and can be thought of as a control service rather than an energy service. As units depart from their operating points, they temporarily supply or consume balancing energy. The CAISO procures regulation up and regulation down separately. Regulation up increases generation output (or decreases in load). Regulation down decreases generation output (or increases in load).

The CAISO requires that Regulation Reserves:

- Reach the maximum amount of Regulation offered within 10-30 minutes.
- Be capable of receiving a direct, digital, unfiltered control signal generated from the ISO Energy Management System through a standard ISO direct communication.
- Provide an instantaneous response to a signal without a manual operator intervention for each minute of control response.
- Send dynamically-monitored signals to EMS regarding actual power output (MW), high limit, low limit and rate limit and in-service status indication.
- Maintain primary and backup voice communication between ISO control center, Scheduling Coordinator, and Operator (CAISO 2010c).

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[5] WECC Standard BAL-STD-002-0 – details the requirements for operating reserves and can be found here: http://www.wecc.biz/Standards/Approved%20Standards/BAL-STD-002-0.pdf

[6] Among other things, a contingency event could be triggered by the loss of a generator, transmission asset or line, or the result of a large load forecast error.

5.1.2 Spinning Reserves

Spinning Reserves are resources that have the capacity to increase or decrease production according to a dispatch signal. Spinning Reserves must begin to respond to a grid disturbance instantaneously and be able to reach their maximum amount offered within 10 minutes.

Current requirements for Spinning Reserves are:

- A minimum governor performance of 5% droop, dead band +/- .036 Hz. The power output must change within one second for any frequency deviation outside the governor dead band.
- The resource operator must have a means of receiving dispatch instructions to initiate an increase in real power output (MW) within 1 minute.
- The resource must be able to increase real power output (MW) by the maximum amount of Spinning Reserve to be offered within 10 minutes.
- There must be primary and backup voice communication between the ISO Control Center and the Operator (CAISO 2010c).

5.1.3 Non-Spinning Reserves

Non-spinning Reserves are similar to Spinning Reserves, except that the response does not need to begin instantaneously. However, the resource must still be able to reach their maximum bid amount within 10 minutes.

The current requirements for Non-Spinning Reserves are:

- The resource must be able to increase output or disconnect load indicated in the dispatch instructions within 10 minutes.
- The resource operator must have a means of receiving dispatch instructions to initiate an increase in real power output (MW) or disconnect load within one minute (CAISO 2010c).

5.2 Summary of Ancillary Services

Table 1 describes each ancillary service in the context of the CAISO market with the following attributes:

- **Response time** defines how quickly a resource must respond to the ISO's dispatch signal.
- **Duration** defines how long the resource must be able to provide the energy behind its awarded capacity. Capacity is awarded for 60 minutes in the Day-ahead market and 15-minutes in the Real-time Market. This is distinct from the duration required for the energy dispatch behind the awarded capacity amount.

For spin and non-spin, the current duration for the energy dispatch is currently 2 hours. Upon FERC approval, the CAISO will be changing the energy dispatch duration requirement to 30 minutes.

- **Market Cycle** defines how frequently the capacity service is purchased by the ISO. Ancillary Service capacity is procured in the CAISO's real-time market through the Real Time Unit Commitment (RTUC) application. RTUC is part of the CAISO's real time market and it runs every 15 minutes and commits Fast Start resources and Medium Start resources. If energy is needed from a spin and non-spin capacity award, the energy behind that capacity is dispatched through the CAISO's Real-time Dispatch (RTD) application in the 5-minute energy market.
- **CAISO market** identifies the market in which the services are purchased.
- **Price Range** where applicable, defines the average, minimum, and maximum price in dollars per megawatt hour.

Table 1. Ancillary Service in the CAISO market

SERVICE	Response Time	Duration	Market Cycle	CAISO Market	Price Range $/MW-hr (Jan-Dec. 2009) Yearly Average	Min	Max
	Description						
REGULATION UP:	*Online resources that can increase their actual operating level in response to a direct electronic Automatic Generation Control (AGC) signal from the CAISO to maintain standard frequency in accordance with established reliability criteria. Once load is eligible to provide regulation, Regulation Up would be a decrease in load from its current operating level.*						
	<1 minute; must be able to reach Regulation bid amount within 10-30 min	15 min (Real Time); 60 Min (Day Ahead)	Day-ahead (1 hour); Real-time (15 min)	Day-ahead & Real Time Market	*7.51*	*1.90*	*41.00*
REGULATION DOWN:	*Online resources that can decrease their actual operating level in response to a direct electronic Automatic Generation Control (AGC) signal from the CAISO to maintain standard frequency in accordance with established reliability criteria. Once load is eligible to provide regulation, Regulation Down would be an increase in load from its current operating level.*						
	<1 minute; must be able to reach Regulation bid amount within 10-30 min	15 min (Real Time); 60 Min (Day Ahead)	Day-ahead (1 hour); Real-time (15 min)	Day-ahead & Real Time Market	*6.01*	*2.00*	*19.00*
SPINNING RESERVES:	*A portion of unloaded capacity on a resource that is synchronized to the grid that is instantaneously responsive to system frequency and that is capable of being loaded to its awarded capacity amount within ten minutes. When loads are eligible to provide spinning reserve, this will be load that can be curtailed to their awarded capacity amount within ten minutes and have a frequency response capability, i.e. can respond to under frequency conditions.*						
	Instantaneous response; <10 minutes for full output	30 minutes	Day-ahead (1 hour); Real-time (15 min)	Day-ahead & Real Time Market	*4.23*	*1.50*	*38.00*
NON-SPINNING RESERVE:	*A resource that is capable of being synchronized to the grid and can be loaded to its awarded capacity amount within ten minutes. Loads that provide non-spinning reserve must be capable of curtailing to their awarded capacity amount within ten minutes.*						
	< 10 minutes	30 minutes	Day-ahead (1 hour); Real-time (15 min)	Day-ahead & Real Time Market	*1.42*	*0.25*	*35.00*
	Other Services (Not procured through ISO Market, but through reliability contracts)						
VOLTAGE SUPPORT:	*The injection or absorption of reactive power to maintain transmission-system voltages within the required range.*						
	Seconds	Seconds	Years	NA	NA		
BLACK START:	*Generation, in the correct location, that is able to start itself without support from the grid and which has sufficient real and reactive capability and control to be useful in energizing prices of the transmission system and starting additional generators.*						
	Minutes	Hours	Years	NA	NA		

Source: Adapted from (Kirby 2006) with definitions, timeframes and prices from (CAISO 2010c, CAISO 2009b).

5.3 CALIFORNIA WHOLESALE MARKETS[7]

The CAISO purchases AS in both the Day-Ahead and Real Time markets.

The CAISO procures both energy and AS in the Day-ahead market. The Day-ahead market opens seven days before and closes at 10:00am the day before the trading day. Results are published sometime after 1pm (13:00) the day before the trading day. The Day-ahead market utilizes three processes to ensure that load is reliably served at the least cost. First, the Market Power Mitigation-Reliability Requirements Determination (MPM-RRD) develops a "bid pool" or resource stack, ensuring that there are no constraints (i.e., transmission, congestion), and that "must run" units are included. (DR is currently not subject to MPM) The results from the MPM-RRD are utilized in the Integrated Forward Market Process.

The Integrated Forward Market (IFM) process produces binding energy and ancillary services schedules. While 100% of the CAISO-forecasted ancillary services requirements (as defined by WECC) are purchased in the IFM, only bid-in supply and bid-in demand for energy are cleared. If the total amount of energy procured in the IFM does not meet the CAISO forecasted demand, the additional capacity is purchased through the Residual Unit Commitment (RUC) process. The RUC process ensures that sufficient supply is available in the Real-Time Market to meet the demand forecasted by the CAISO. Units awarded under RUC must submit an energy bid into the Real-Time Market.

The Real-Time Market procures balancing energy to meet instantaneous demand, reduces supply if demand is insufficient and secures additional ancillary services to comply with WECC requirements. The Real-Time Market involves five processes: Market Power Mitigation-Reliability Requirements Determination (MPM-RRD), the Hour Ahead Scheduling Process (HASP), the Short-Term Unit Commitment (STUC), the Real-Time Unit Commitment (RTUC), and Real –Time Economic Dispatch (RTED). The RTED provides the actual incremental/decremental (INC/DEC) instructions. The CAISO utilizes the Automated Dispatch System (ADS) to issue all binding dispatches for the Real-Time Market. Our experiences from the field tests for this project will allow us to understand if DR resources can participate in Real-Time Energy Market.

The Real-Time Market posts Day-ahead market results upon opening the day before trading occurs at 1pm (13:00) and upon closing 75 minutes before the trading hour. The Real-Time Market utilizes the same inputs and tools as the Day-ahead market, and runs the MPM-RRD to develop a real-time "bid pool". However, the time horizon for the Real-Time Market is a single trading hour, instead of a full day. In the Real-Time

[7] Market section is adapted from CAISO training materials. Peterson, J. "ISO Markets Overview." 2010. www.CAISO.com

Market, the results from the MPM-RRD "bid pool" are inputs into the Hour-Ahead Scheduling Process (HASP). The HASP run results in binding pre-dispatch schedules for the interties, and advisory schedules for generators.

The third process that runs in the Real-Time Market is the Short-Term Unit Commitment (STUC). The STUC runs once per trading hour and considers four hours ahead as it begins to commit medium start resources.

The fourth process in the Real Time Market is the Real-Time Unit Commitment (RTUC). Running in 15 minute cycles, RTUC issues start up instructions for quick and medium start resources and shut-down instructions for units no longer needed. The RTUC also procures contingency-only ancillary services on an as-needed basis.

The final process of the Real-Time Market is Real-Time Economic Dispatch (RTED). RTED utilizes the Very Short Term Load Predictor (VSTLP) forecast to dispatch balancing energy every five minutes. RTED also provides the actual incremental/decremental (INC/DEC) instructions. In Real-Time, the CAISO may also utilize Contingency Dispatch to convert ancillary services capacity into energy. Contingency dispatches are done in real time in the event of a localized grid disturbance or system emergency. Contingency dispatches can also be converted into balancing energy if there is a scarcity of balancing energy (Pedersen 2010).

6 USING DR TO INTEGRATE RENEWABLE GENERATION

Unlike conventional reliability based DR that is generally available for a limited number of hours during defined summer peak periods, to facilitative renewable integration, DR needs to be available more hours throughout the year and provide a wider range of load response. In addition to load reductions on hot summer afternoons, DR may need to provide increases in load. In addition, DR must be able to respond slow (day ahead), fast (10 minute) and instantaneous (less than 5 minutes) intervals. This type of demand response will typically require an aggregated portfolio approach that includes multiple resources with individual response characteristics.

A portfolio approach identifies the characteristics of controlled loads across participating sites and dispatches the appropriate loads to meet the ISO's instructions. The portfolio works in aggregate to:

- Operate **year round** and be available in all hours
- Provide **fast and instantaneous** DR
- Provide not only **load reductions** (Regulation Up), but also **increases in load** (Regulation Down)

This portfolio approach is important to mitigating the combined variability of wind and solar generation. The integration challenges and market opportunities created by variable generation are not confined to a particular season or time of day. Variable generation profiles are weather-dependent; likewise, loads exhibit weather sensitivity and seasonality. Table 2 maps the challenges to seasonality.

Table 2: Integration Challenges by Season

Challenge	Spring	Summer	Fall	Winter
The magnitude of hourly overall ramping requirements	x	x	x	
Regulation capacity and intra-hour variability	x	x	x	x
Over-generation	x			
Large, near-instantaneous production ramps		x	x	

In order to build DR resources that are available in all seasons, this project will match DR strategies and end-uses to each area of system need. For example, over-generation in the spring due to hydro generation and low customer load levels provides price-sensitive industries with opportunities to take advantage of low or even negative energy prices.

We categorize DR according to the response time as slow, fast and instantaneous. Slow DR is when a facility is notified a day ahead and has to deliver load response the next day or hours after the notification. Fast DR is when facilities have to deliver their response within minutes. Finally, instantaneous DR is when a facility has to deliver the response within seconds. As the notification time increases, the duration of the event also seem to increase in various programs that are offered in the nation.

Fast DR is needed to smooth intra-hour variability of wind and solar. As the PLP project demonstrated, DR can provide fast, reliable load reductions within the requirements for non-spinning reserves. For some loads, such as HVAC, the short, fast responses needed to reliably provide ancillary services are ideal since the primary service (i.e. cool air) is not noticeably affected. To address intra-hour variability, this project will build on the experience of providing non-spinning reserves and utilize the AGC signal to provide regulation up and regulation down. To achieve the requirements for regulation, it may be beneficial to combine instantaneous response end-uses such as lighting with fast response resources such as HVAC systems.

6.1 END USES OF INTEREST

Extensive AutoDR field tests in California since 2003 showed that two types of strategies, namely scaling down and switching off commercial building end uses, result in different response times. While many of the buildings' electric data came from interval meters that captured data in 15 minute intervals, several sites had submetering equipment and PLP sites had four second telemetry installations. Below table summarizes the end uses for commercial buildings, type of response and the response time for various strategies. While the table only refers to reducing loads, the same systems can be used to increase loads as well. However, energy used to increase loads should be prioritized for storage and not wasted:

Table 3. End use response time characterization in commercial buildings

End Use	Type of Response		Response Time	
	Scaling Down	**Switching Off**	**Scaling Down**	**Switching Off**
HVAC	Global temperature adjustment, Decreasing duct static pressure, etc.	Turning off compressor(s), chiller(s), etc.	Less than 2-5 minutes	Seconds
Lighting	Dimming down lights	Turning off lights	Less than one minute	Seconds
Plug Loads	N/A	Turning off equipment	N/A	Seconds
Miscellaneous Electric Loads		Turning off power		Seconds

DR can also be utilized to provide load increases as well as reductions. Load increases act like regulation down, and can provide a needed sink for excess renewable generation. Flexible loads with storage capability are especially well suited for this kind of response.

Based on the DR resource characteristics identified above, the DRRC research team identified the following end-uses[8] in California for further study:

- Ventilation
- Air conditioning

[8] Electric heating is excluded as its penetration in California is low.

- Thermal energy storage
- Industrial refrigeration
- Lighting
- Wastewater treatment
- Water pumping/supply
- Year-round/seasonal product manufacturing

These end-uses are well-suited to the IRR pilot because they combine flexible loads or production times with some form of storage (thermal or process mass). Of these end-uses, the first four emerged as the best candidates for the implementation phase of the pilot. They were selected because they exhibit at least one of the following:

- Significant storage component
- Low load and shed variability to enhance forecasting
- Ability to deliver resource within 10 minutes
- Industry adoption of sophisticated energy management and controls capability
- Scalability: they represent a significant load in PG&E's service territory

Table 3 illustrates the type of DR that three industrial loads would be well suited for. The numbers indicate recommended prioritization based on prior studies.

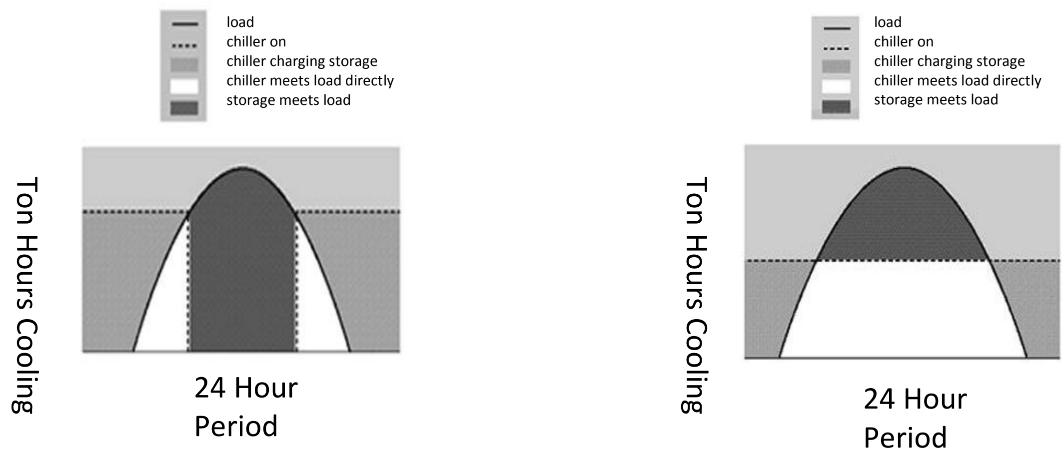
Table 4: Prioritization of Potential End-uses

DR Strategy	Instantaneous (Same hour)	Fast (Same Day)	Slow (Day Ahead)
REFRIGERATED WAREHOUSE			
Precooling		2	1
Short term shutdown	3		
WATER PUMPING			
Municipal Water Pumping	2 (w/ storage)	3	1
Agricultural Pumping		1	
WASTEWATER TREATMENT			
Storage		2	1
Over oxygenation		3	
Scheduling			1

6.1.1 THERMAL ENERGY STORAGE SYSTEMS (TES)

The primary usage of Thermal Energy Storage Systems (TES) is to shift cooling loads. Storage media, such as ice, water or a working fluid are chilled during times of low demand for cooling. During high demand periods, the cooling energy stored within the system is released, offsetting usage of the normal HVAC unit. Full storage system will meet the entire cooling load during peak period. A partial storage system will meet a specified portion of peak cooling load, as illustrated in Figure 5.

Figure 5: Illustration of operation of full storage TES (left) and partial storage (right)



Source (Pacific Gas and Electric Company 1997)

ICE AND CHILLED WATER SYSTEMS

The two main types of TES systems widely in use are ice and chilled water systems. Chilled water storage systems typically require more space for the tank and related infrastructure than ice water storage systems. They are generally more appropriate for large industrial buildings and complexes. The design of a system is site-specific. The economies of scale that make these systems most cost-effective begin roughly around 10,000 ton-hours of cooling. These large systems are the most efficient of all TES systems in the conversion of electricity to ton-hours cooling and have a charging cycle of 5-6 hours[9]. Ice storage systems are often a more useful solution for smaller commercial buildings with less cooling load and size constraints. Customers can choose from a variety of commercially available ice storage systems that can be installed and integrated into a buildings' EMS. The typical charge cycle for ice systems is 10-12 hours[10].

Chilled water systems typically are a good solution for large buildings and complexes where size of the storage system is not a constraint. University and Community College

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[9] From interviews with various TES manufactures and control system designers.

[10] From interviews with various TES manufactures and control system designers.

campuses with a commitment to environmental awareness are often prime candidates for central chilled water plants. Also, large institutions and other owner-built buildings are better situated to outlay the large amounts of capital necessary to fund them, as they can recoup their initial investment over a longer period of time.

Generally, chilled water cooling systems are an attractive option when:

- there is a large differential between average and peak cooling load
- peak rate charges are high
- peak load is mostly thermal-induced
- buildings benefit from alternate uses of chilled water, such as using the stored water to provide some or all of the fire protection water storage.

TES/Wind Generation

While both ice and chilled water systems could be utilized for the IRR pilot, several factors make chilled water storage system more appropriate than ice storage for integration with wind. First, the shorter charge cycle (5-6 hours) provides increased flexibility to charge faster or slower depending on the amount of wind available on the grid. Charging cycles can be adjusted through the set points on the chillers, the flow rate, the cycle rate and the pump speed, with minimal impacts on total efficiency.

Second, the economies of scale from using chilled water storage make for a more cost-effective option. Accommodating increased amounts of wind capacity require sizing of a tank for the maximum amount that you wish to charge. Chilled water systems are more practical than ice systems for this purpose due to the lower marginal cost of operation at higher volumes.

Furthermore, TES systems are an efficient method of load shifting. An optimally designed system can be 80-90% efficient at shifting from peak to off-peak (8-12 hours). For comparison, flywheels generally see efficiencies of around 80% over 15 minutes; pumped hydro averages around 72% over the span of an entire season. This makes TES systems one of the most efficient, cost-effective options for storing wind energy produced at night.

Case Study: UC Merced

A study was conducted in 2009 by the PIER Demand Remand Response Research Center at UC Merced to assess the potential for demand response in a TES setting. UC Merced uses a two million gallon chilled water full storage system to flatten the campus cooling load profile during peak demand periods. On a daily basis, a total of one-fourth of the entire campus load, or 1.2 MW is shifted by the system. A key finding of the study was that even with full off-peak storage cooling in use, UC Merced was able to shed an additional 13% of their load, or 183 kW, during demand response events. This confirms that there is additional flexibility in buildings with full storage TES systems (Granderson 2009).

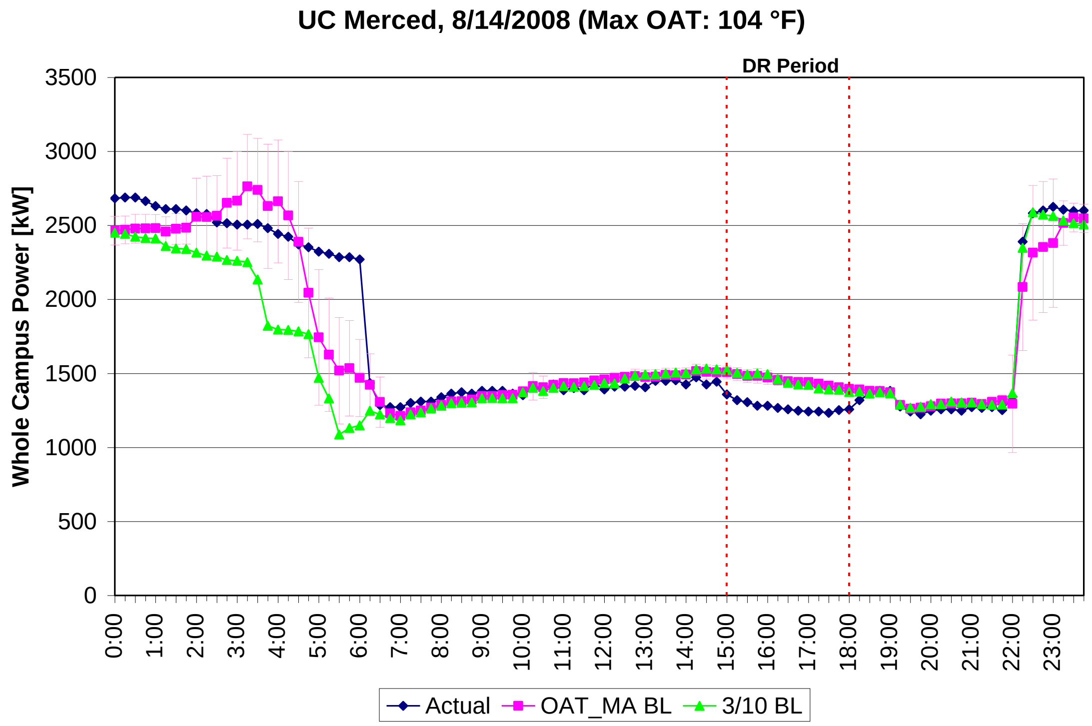

Figure 6: Demand Response with a TES System

6.1.2 PG&E's Permanent Load Shift Program: "Shift and Save"

In 2007, PG&E began a $10 million effort to encourage its customers to utilize TES systems for shifting cooling loads. The program aims to utilize chilled water and ice storage systems to shift a total of 7.9 MW of cooling loads among industrial, commercial, agricultural and large residential customers. Administered by Trane and Cypress Ltd, customers are offered rebate incentives for curtailing peak load and can also save energy. Rebate incentives are based on the amount of peak demand load that is shifted (in kW) and range from $500-$2000/kW depending on the technology employed and whether the system is new or retrofitted. Energy savings are site specific and depend to a greater degree on system design.

6.2 Industrial Loads

In this section, we identify four industrial sectors with significant potential to participate in integration of variable renewable resources: refrigerated warehouses, wastewater treatment, and water pumping for municipal water supply. These sectors all have experience with DR, demonstrate significant magnitude of capacity that can be used for energy storage and provision of ancillary service products. This section summarizes some of the issues around DR in these three sectors and discusses their potential to contribute to increased renewable integration.

6.2.1 Industrial Refrigerated Warehouses

Refrigerated warehouses in California represent a large electrical load. Because of the massive inherent thermal energy storage potential that refrigerated warehouses possess, they make excellent targets for demand response and a good resource to integrate wind and solar energy.

According to the 2009 LBNL Study *Opportunities for Energy Efficiency and Automated Demand Response in Industrial Refrigerated Warehouses*, refrigerated warehouses in California have a theoretical potential demand reduction of 43-88 MW (Lekov et al. 2009). Total California demand is about 360 MW (Prakash et al. 2008) and is comprised of approximately 220 large refrigerated warehouses. The total capacity is 12 billion cubic meters (412 million cubic feet), representing about 13% of the total refrigerated warehouse volume in the US (USDA 2008).

In order for refrigerated warehouses to be a successful renewable integrating resource, adequate temperatures to maintain product quality are needed. Using refrigerated warehouses as energy storage entails deliberately allowing temperature fluctuations as the system charges and discharges. Some products are better suited to such fluctuations than others. For example, frozen packaged products, frozen juices, and frozen products that do not require a minimum temperature are good candidates for demand response strategies, since they can tolerate a 5°F temperature drift (Pacific Gas and Electric Company 2007). In contrast, cooled products may not tolerate temperature variations larger than 2–3°F and humidity variations greater than 3–5% (American Society for Heating Refrigeration and Air-Conditioning Engineers (ASHRAE 2006). Warming and re-cooling may also result in ice crystal growth within the products (Singh).

Fortunately for IRR, freezers are more flexible and make up more of the total area in refrigerated warehouses. In the US, freezer space comprises 78% of total warehouse area while cooler space occupies the remaining 22% (Prakash et al. 2008).

Using refrigerated warehouses to integrate renewable energy sources will require load shifting strategies that shape the load to coincide with availability (or excess/shortages in generation capacity). For example, during periods of low availability of variable renewable resources, cold storage set points may be increased, HVAC loads can be reduced, or VFD-enabled equipment could be reduced. California's 2008 Title 24 requires the use of VFDs for all new refrigeration systems (California Energy Commission 2008).

While the particular products in the warehouse determine the amount of allowable temperature fluctuation, additional factors matter. Insulation, traffic, activity in the warehouse, weather, lighting, and thermal mass of the products all play a significant role in determining how fast temperature drift occurs when cooling systems are shut down.

Some refrigerated warehouses have the ability to sub-freeze or overcool. The ability to pre-cool depends on the factors that cause temperature drift and the capacity of the refrigeration system. The refrigeration equipment must be able to withstand the higher refrigeration load during pre-cooling periods (Stoeckle 2000).

Energy efficiency measures help attain the most energy storage out of a refrigerated warehouse resource. Measures such as improving insulation and loading-dock dehumidification deliver energy and demand savings as well as reduce the temperature drift during DR events. More sophisticated control systems that are used for energy efficiency and load management may also enable OpenADR participation at little or no additional cost.

Several control system types are encountered in refrigerated warehouse facilities: standalone controls, distributed control systems (DCS), and integrated control systems such as Supervisory Control and Data Acquisition systems (SCADA). SCADA systems have the best communication capabilities for automated demand response applications in industrial refrigerated warehouses. These communication capabilities make refrigerated warehouses with integrated centralized control systems excellent candidates for OpenADR by bringing together the actions of the individual equipment controls and locally distributed controls. Such integration allows the OpenADR infrastructure to interact with a single control system instead of multiple systems (e.g., DCS), thus creating a cost-effective and easy to manage reliable base for OpenADR implementation.

6.2.2 Wastewater Treatment

Municipal and industrial wastewater treatment facilities are energy intensive facilities that may have the ability to reduce demand during periods of constrained supply. They also have the potential to shift loads, making them candidates for integration of variable renewable generation.

Water and wastewater treatment in the United States uses between 75,000 to 100,000 GWh annually (Consortium for Energy Efficiency 2006; Environmental Protection Agency 2008). In California, wastewater treatment used about 1,600 GWh of electricity in 1995 and 2,012 GWh in 2001 (Klein et al. 2005). Load of this sector is projected to increase 20% over the next 15 years with population increases and more stringent regulations (Environmental Protection Agency 2008).

Wastewater treatment facilities are excellent candidates for automation of DR using OpenADR, with major demand responses opportunities in the food processing industry and municipal facilities (Lekov 2009). According to the EPA, there are 1,716 wastewater treatment facilities which have received NPDES permits for discharging wastewater. Of these, 373, or 22%, are categorized as food processing facilities and 336, or 20% are categorized as municipal wastewater treatment facilities (Environmental Protection Agency 2009).

Wastewater treatment facility loads vary widely depending on time of day, day of week, season, type of industry, location, and population (Tchobanoglous 2002). Facility loads also differ because of the quality of the waste stream and the stringency of regulations. (Klein et al. 2005). These facts further demonstrate that DR resources must be flexible and available 24 hours a day in order to be integrated with renewable resources.

Particularly interesting targets for further study are those facilities that have already implemented energy efficiency and load management technologies. In some cases, these facilities already have control technologies in place that can be adapted for automated demand responses at low cost. Lekov et al hypothesize that facilities participating in energy efficiency programs will be more, not less, likely to initiate OpenADR and load management actions because they will have a more complete understanding of their energy use.

Similar to refrigerated warehouses, wastewater facilities also require sophisticated control systems in order to effectively participate in automated demand response. SCADA systems provide improved operational efficiency, in addition to facilitating automation of DR. The current worldwide market for SCADA systems for water and wastewater industries is expected to increase at a compounded annual growth rate of 5.4% from 2007 to 2012 (ARC Advisory Group 2007). SCADA systems provide numerous benefits to wastewater treatment facilities such as the ability to monitor and control remote equipment, schedule operations, and automatically start and stop devices. These features result in more efficient operation of equipment--aerators, blowers, pumps, valves, chemical feed systems (Lekov et al. 2009)--and facilitate integration with OpenADR.

6.2.3 Food Processing

Energy consumption in the food processing area is highly variable by season, particularly in the fruit and vegetable sector. Wastewater in this sector varies in composition and volume, depending on the product, scale of operation, weather and season (Phillips 1997). Tomato and peach industries use most of the water during summer months and peak in August. Most other fruit and vegetable industries follow similar trends (Mannapperuma 1993). In 1999, food processing facilities in California had a coincident peak load of 0.3 GW (Brown R. and J. Koomey 2003).

6.2.3.1 Demand Response Strategies

Wastewater treatment facilities are subject to a variety of federal, state, and local regulations. It is critical that effluent quality is maintained to satisfy these regulations as DR strategies are executed. Since wastewater facilities need to adhere to regulations at all times, the DR strategies available to them mainly fall within load shifting (moving loads to different hours), rather than shedding (reducing total service delivered). In order to integrate variable renewable resources, electrical loads will need to be able to respond quickly. Fast response from a wastewater treatment facility requires real-time control.

- **Storage:** If wastewater facilities have storage capacity, they can store untreated wastewater and process it when electricity prices are lower. If facilities do not already have storage capacity, building new storage specifically for this purpose may not be cost effective. Storage of untreated wastewater may not be possible for some industrial facilities if wastewater contains reactive chemicals.
- **Scheduling:** Facility processes that are scheduled can be potentially rescheduled to times of lower electricity prices and turned off when supply is constrained. Some wastewater processes that can be rescheduled include dewatering, anaerobic digestion, and backwashing filtration systems (Electric Power Research Institute 1994).
- **Backwash Filter Pumps:** Shifting operation of backwash filter pumps to off-peak hours can reduce on-peak demand. This strategy is only suitable in cases where the turbidity of the wastewater is low enough to allow operation without backwashing (Electric Power Research Institute 1994). Instrumentation and controls are required to monitor filter status.

When there is storage capability, large load reductions can be seen by targeting effluent pumps and centrifuges. However the reaction of effluent turbidity to reduced aeration load, along with the cogeneration capabilities of municipal facilities, including existing power purchase agreements and utility receptiveness to purchasing electricity from cogeneration facilities, as well as economics of DR programs are limiting DR participation of this sector (Thompson et al 2010).

6.2.4 WATER SUPPLY

Hirst (2002) and Eto (2002) both mention using large municipal water-pumping systems as a flexible load that could provide reliability services. Water systems typically have tanks, reservoirs, or lakes which store water for later distribution to consumers. Such water systems are ideal reliability loads; they can reduce pumping loads for up to a few hours while still delivering the services that water customers demand by letting gravity do the work during non-pumping hours. With control systems and adjustable speed drives, the power consumption of pumps could be varied to track power coming from variable sources of renewable energy.

Electrical demand from water supply-related loads exceeds 2000 MW on peak days in California, with agricultural groundwater and surface water pumping making up about 60% of the demand (House 2006). Such large electrical demand related to water supply makes this sector a target of interest for demand response. While demand from water supply during peak hours is about 25% lower than the non-coincident peak, the size of the load and its flexibility make it worthwhile for further study. Chew stated in 2007 that demand is expected to grow by as much as 3500 MW over the next ten years.

There are a variety of potential methods for shifting water supply-related electricity demand. Policies could be aimed at reducing water demand during periods of constrained electricity supply through measures such as time-of-use water rates. Alternatively, water storage could be used to a greater degree. If residences statewide shifted one half of their water use out of the on-peak period, a total of 300 MW of on-peak electricity could be saved (House 2006). While time-of-use water metering is technically possible, water agencies have not identified incentives sufficient enough to warrant investment in the considerable infrastructure necessary for time-of-use water pricing.

Water storage offers the potential to reduce electricity demand during periods of constrained supply and increase demand during periods of excess supply. Water storage provides additional benefits such as improved water system operations, fire fighting assistance and earthquake response. Using water storage near electrical loads also improves grid operations by reducing transmission losses and improving voltage control (House 2006). With additional water storage in urban areas, peak demand could be reduced by another 1,000 MW (California Energy Commission 2005). This storage resource could also be used for renewable integration.

Water storage is a known and proven technology that water agencies are already acquainted with. Pumped water is also a low-tech and possibly cheaper method of energy storage compared to batteries or flywheels. Additional research and experimentation is required to see how water agencies would respond to increased storage for renewable integration. While many water agencies have locations reserved for additional water storage facilities, sufficient incentives do not yet exist to install additional storage to shift electricity demand. Additional research is necessary to identify what incentives would be required for water agencies to install additional storage for demand response purposes (House 2006).

For the purpose of using water storage for renewable integration, additional research is necessary. Studies must be done to quantify the number and size of currently available unused storage sites and to determine how quickly facilities can respond to DR events (House 2006).

Flexible end-use resources can provide the storage and fast response needed to integrate variable generation. This pilot will focus on chilled water HVAC systems, thermal mass in buildings, refrigerated warehouses (particularly frozen products), water pumping, and wastewater treatment. These building types were selected because they have large, flexible loads, potential scalability and past experience with automated demand response. However, this pilot could be expanded at a future date to include cement manufacturing, air separation, agricultural pumping, industrial process, and others.

7 Field Test

7.1 Goals and Objectives

The IRR field tests will use DR resources to evaluate three objectives:

- Smoothing intra-hour variability
- Forecast error
- Absorbing excess renewable energy during over-generation periods
- Addressing morning and evening ramping periods

Focusing on these challenges involves identifying the appropriate indicators, signals and responses to address each challenge. These may be the same or different for each challenge. CAISO market products currently do not exist for some of these services since emerging storage and DR technologies have not been widely deployed. Thus, the ideal signaling and market structures are not in place (ie, there is currently no "Ramping" product). While the CAISO may need to identify new market products that will facilitate variable generation integration and relieve other constraints, without understanding how different resources can participate, the CAISO is reluctant to define a new market product. This pilot will provide the necessary testing and demonstration to inform the creation of these new market products.

The three major goals of the field tests are:

1. To evaluate the representation of demand-side resources as CAISO ancillary services products;
2. To translate the representation of ancillary services product(s) that help with intermittency to customer-side automated demand response signals using OpenADR; and
3. To evaluate the feasibility of demand-side resources to address these needs.

During the preparation period before the field test, the team will discuss and evaluate the best representation of CAISO ancillary services product features that it will need to integrate intermittent renewable resources. The representation will have to work with the existing products and systems as well as fit within the future framework of renewable portfolio standards in California. Once a product (or a set of products) is identified, the team will concentrate on establishing an automated link between the CAISO systems that trigger these resources and the OpenADR information exchange model. If an actual link is not feasible, the team will use simulated signals to trigger DR. OpenADR is currently established to represent price and reliability information so these products will be translated to currently available representations. Finally, a variety of commercial buildings and industrial facilities with active and/or passive storage systems will be recruited and enabled to receive the OpenADR signals that represent intermittent renewables integrated in the electric grid.

7.2 METHODOLOGY

The field tests will be designed and delivered to address the goals and objectives. In this section, we outline the methodology in three areas: communication, automation and demand-side evaluation.

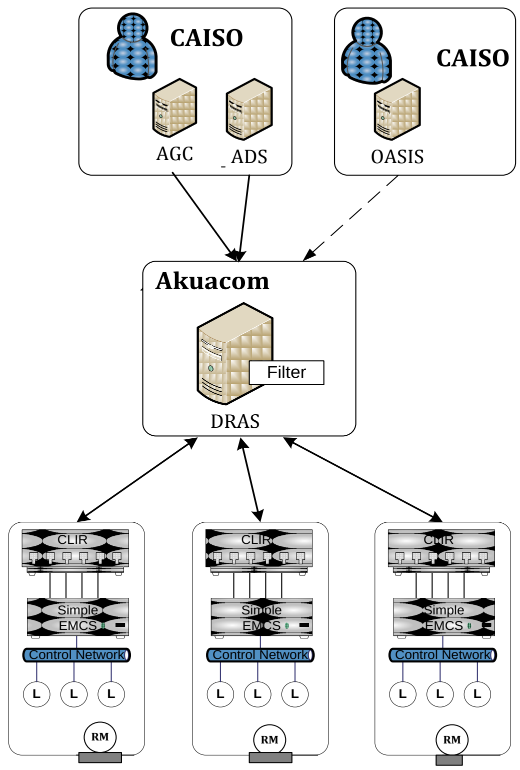

Figure 7. Architecture for the field tests

Initial discussions with the CAISO indicated that the following existing ancillary services triggers could possibly be used to represent the challenges with renewables:

- Automated Generation Control (AGC) for intra-hour variability
- Automated Dispatch Signals (ADS) for ramping and intra-hour variability

For the duration of the project, the Open Access Same-time Information System (OASIS) will be monitored to evaluate the impact of forecast error and over generation on the wholesale electricity prices.

The actual implementation will depend on if and how CAISO can trigger these systems without affecting the actual market transactions. When one or more of these systems are triggered, the algorithms within the DR automation Server (DRAS) will prioritize and filter the information and translate it to OpenADR. The sites will receive the information in the OpenADR information exchange format and trigger pre-programmed algorithms.

For each site, the control systems will be pre-programmed to trigger DR strategies that are appropriate for the type of signals (price, reliability, slow or fast DR) they receive. The AGC signal communication will be conducted on a secure and private network. The ADS may use the same private network as AGC or the existing Internet connection from the PLP study with standard 128-bit Secure Socket Layer (SSL) encryption to ensure security of these transactions.

On the demand-side, the team is planning to recruit 3-5 sites with passive or active storage systems. The field tests will be conducted during the spring, summer and fall of 2011. The storage systems are expected to range from thermal mass to chilled water thermal energy storage systems. The team will evaluate the use of production storage capabilities of the industrial sites for mitigating the effects of intermittency. Each facility's end uses will be evaluated for its appropriateness for the triggers available.

The number of events will depend on the actual conditions of the grid. However, in the case that CAISO system can not issue test triggers, the team is in discussion about issuing these through the DRAS so as to evaluate the performance of the end uses at each facility.

The meter data will be collected through the InterAct and evaluated using baselines that are appropriate for the type of facilities that participate in the field tests.

The data that is collected from the sites as well as discussions with the industry leaders will be used to extrapolate the aggregated effect of each of these industries. The next step of this research is to consider the aggregation issues of certain types of end uses, industries or customers.

7.3 TIMELINE

The timeline for the activities for the field tests is outline in the table below

Table 5. Timeline for the field tests

Deliverable	Timeline
FIELD TEST PLAN	First Draft August, 2010 Final Draft September, 2010
SITE SELECTION CRITERIA	September 2010
RECRUITMENT AND ENABLEMENT OF UP TO 5 SITES	March 2011
DRAS AND INTERMITTENT LOAD INFORMATION INTEGRATION	March 2011

CONDUCT TESTS	March – October 2011
DOCUMENT SUMMARIZING RESULTS	October – November 2011
SUMMARY OF THE TAG MEETING AND FINDINGS	November-December 2011
Disclaimer: Schedule may change	

8 CONCLUSION

This scoping study summarizes the challenges with integrating wind and solar generation into the California's electricity grid. These challenges are:

- Smoothing intra-hour variability
- Absorbing excess renewable energy during over-generation periods
- Addressing morning and evening ramping periods

In addition to these challenges, there are technical challenges to integrating automation of retail DR triggered by the wholesale conditions. The study describes at a high-level the main types of DR programs available to consumers and CAISO's ancillary services and energy products because an integration of the wholesale and retail requires an understanding of these different offerings and the costs associated with acquiring them. Demand-side active and passive storage systems are proposed as technologies that may be used to mitigate the effects of intermittence due to renewable generation. Thermal mass and chilled water thermal energy storage units are identified as storage opportunities in commercial buildings. For industrial facilities, the study summarizes the opportunities with refrigerated warehouses, wastewater treatment facilities, food processing as well as water supply. However, there are many limitations associated with each industry and use. The field tests will identify and further clarify opportunities and limitations on the demand side. Two ancillary services systems (automated dispatch signals and automated generation control) are identified as providing the triggers for DR enablement. Through the field tests, issues related to communication, automation and flexibility of demand-side resources will be explored and the performance of technologies that participate in the field tests will be evaluated. The major outcome of this research is identifying and defining flexibility of DR resources in commercial buildings and selected industries as well as optimized use of these resources to respond to grid conditions.

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10 ACRONYMS

ADS – Automated Dispatch Signal

AGC – Automatic Generation Control

ASHRAE – American Society for Heating Refrigeration and Air-Conditioning Engineers

CAISO – California Independent System Operator

CDMA – Code Division Multiple Access

CLIR – Client Logic with Integrated Relay

DRAS - Demand Response Automation Server

EMCS – Energy Management and Control System

FERC – Federal Energy Regulatory Commission

HASP – Hour Ahead Scheduling Process

HVAC – Heating, Ventilation, Air Conditioning

IFM – Integrated Forward Market

IRR – Integration of Renewable Resources

MPM-RRD - Market Power Mitigation-Reliability Requirements Determination

NERC – North American Electric Reliability Corporation

OASIS – Open Acess Same-time Information System

PIER – Public Energy Research Program

PLP – Participating Load Pilot

RTD – Real-Time Dispatch Signal

RTED - Real-Time Economic Dispatch

RTUC – Real-Time Unit Dispatch Commitment

STUC – Short Term Unit Commitment

TES – Thermal Energy Storage

VFD – Variable Frequency Drive

VSTLP – Very Short Term Load Predictor

11 Appendix A

11.1 Refrigerated Warehouse Case Studies

11.1.1 Dutch Refrigerated Warehouses

The European Union (EU) and the Sixth EU Framework Program for Research and Technological Development are currently conducting a study using products in Dutch refrigerated warehouses as a storage medium for wind generation. Similar to this project, the aim is to use wind energy when it is available to pre-cool refrigerated warehouse storage areas and then allow refrigerated warehouse temperatures to float, reducing compressor loads (van der Sluis 2008). The preliminary assessment found that varying warehouse product temperatures by even as little as two degrees Fahrenheit could result in significant electricity savings and demand (Butler 2007).

This project combines existing refrigeration technologies and advanced control strategies. The controls utilize software that tracks the refrigeration equipment load and takes into account demand response or electricity price signals. During low price periods, the refrigerated warehouse is pre-cooled using wind energy. During the high price period or during the peak demand hours, the refrigeration equipment automatically shuts off. The temperature setpoint is determined by demand needs and energy prices and is set by a programmable logic controller, which can be installed as part of an existing refrigeration system (van der Sluis 2008).

11.1.2 US Foodservice

The U.S. Foodservice distribution warehouse in Livermore, California stores more than 10,000 products and includes a 32,000 square meter (345,000 square foot) freezer, which maintains temperatures between -18° to -17°C (-1° to 1°F) (Lekov et al. 2009). The entire facility has a typical electrical load of 700–900 kW, with the freezer accounting for 30–40% of the total load.

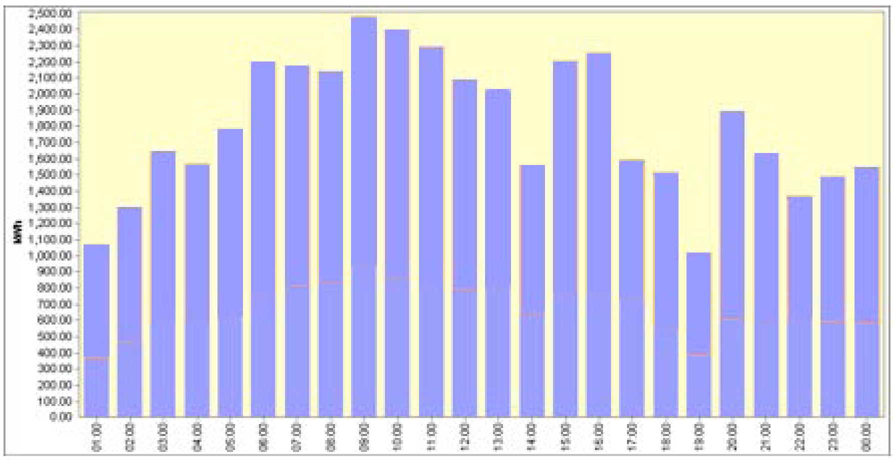
The facility was an excellent candidate for OpenADR participation due to the freezer and HVAC system's stable electrical load, and because it had already installed the controls and communication structure necessary to implement OpenADR.

The facility conducted several test DR events in the spring of 2008, in which the air handlers units serving the freezer were turned off, the temperature setpoint of the HVAC system was raised, and battery chargers were turned off. These strategies enabled the facility to shed about 25% of its total load, and had a maximum load reduction of 330 kW. Turning off the freezer air handlers achieved the largest demand reduction. After a six-hour test event, the air temperature near the doors of the freezer had risen by 8.6°F, and the air temperature of the far walls of the freezer rose 1.2°F, with the temperatures of the product remaining within acceptable limits, and without impacting facility operations.

11.2 Municipal Water Case Study: El Dorado Irrigation District

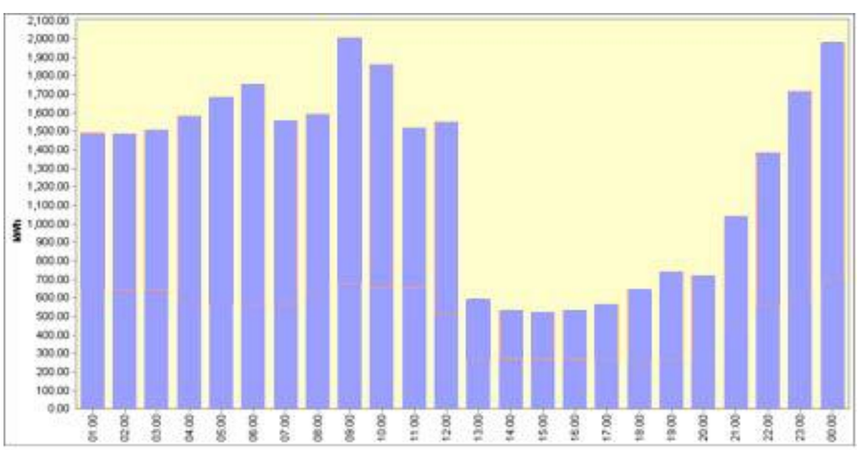
The El Dorado Irrigation District installed an additional 5 million gallon water storage tank in 2005. With the larger storage capacity and allowing the tanks to drop to a lower minimum level they were able to reduce demand during the peak period by 1 MW, or a 60% reduction as shown in the figures below. Additional storage should not increase energy use, and it may reduce energy use if water is pumped to a lower head on average (House 2006, Chew 2007 and California Energy Commission 2005).

Figure 8. June 14, 2004 El Dorado Hills Raw Water Pump Station & Water Treatment Plant Electrical Demand



Source: Chew 2007

Figure 9. June 14, 2005 El Dorado Hills Raw Water Pump Station & Water Treatment Plant Electrical Demand (House 2006)



Source: House 2006